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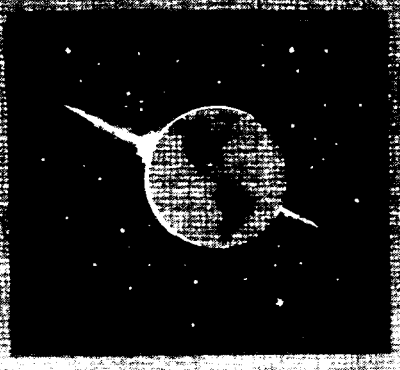

MANNED SPACE FLIGHT TELEMETRY
PCM SYSTEM I

Electro-Mechanical Research, Inc., Sarasota, Fla.
2898005

MANNED SPACE FLIGHT TELEMETRY
PCM SYSTEM 1

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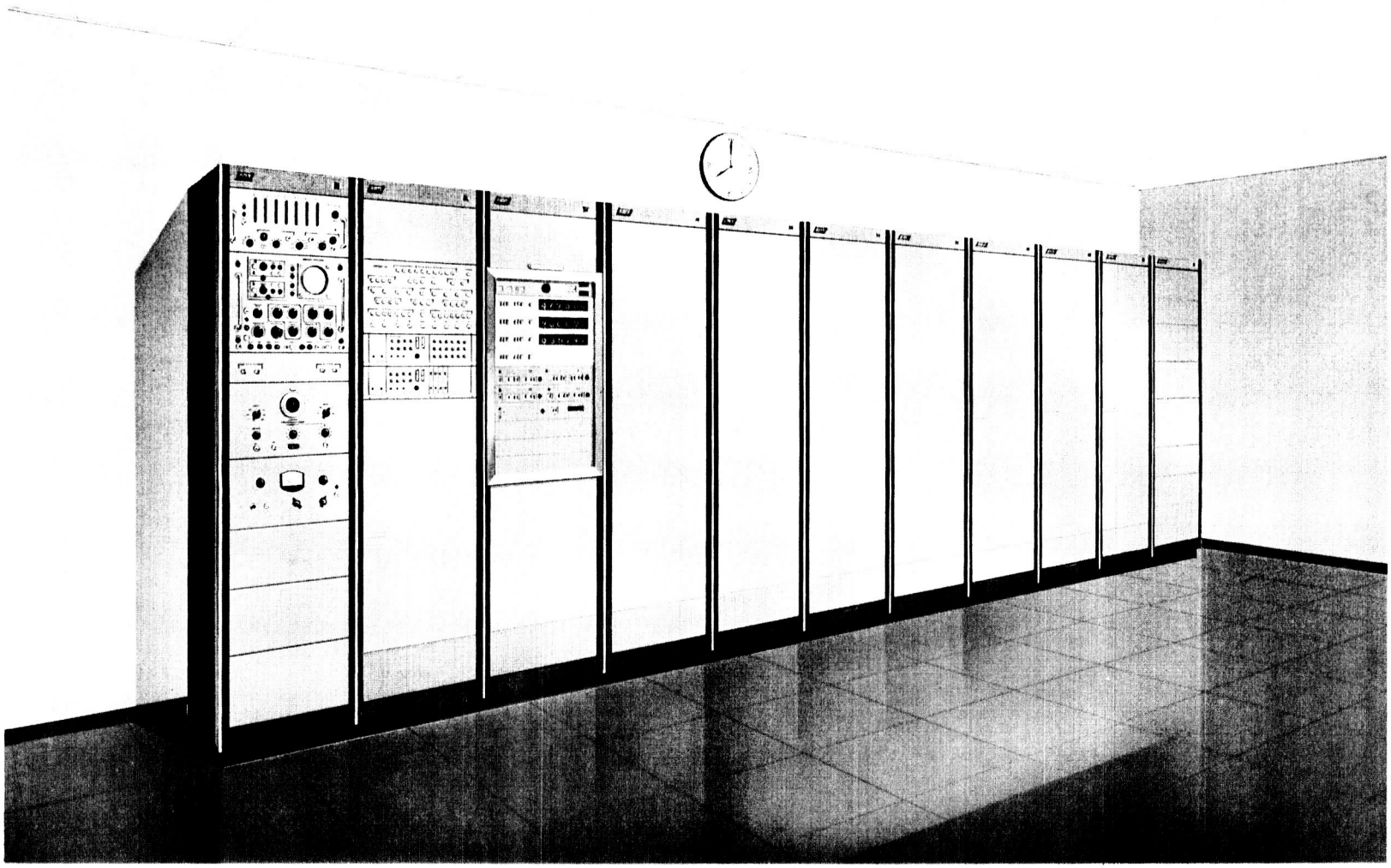

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MANNED SPACE FLIGHT TELEMETRY
PCM SYSTEM 1

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MANNED SPACE FLIGHT TELEMETRY
PCM SYSTEM I

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MANNED SPACE FLIGHT TELEMETRY
PCM SYSTEM I

1. INTRODUCTION

The purpose of this brochure is twofold: to provide the reader who is unfamiliar with telemetry in general and pulse-code modulation telemetry in particular with a brief grounding in these subjects; and to describe NASA's Manned Space Flight Telemetry PCM System I (MSFTP-1) and the problems involved in designing and developing such equipment. Thus the first two sections, "Telemetry in General" and "Pulse-Code Modulation (PCM) Telemetry", are intended for the reader who is not familiar with these topics. The remainder of the brochure is then devoted exclusively to describing the MSFTP-1 equipment in detail.

2. TELEMETRY IN GENERAL

Telemetry means, as the name implies, "measuring from a distance". Thus the process involves taking a measurement at one point, transmitting the information to a second point, and displaying or otherwise using the measurement at this second point. Telemetry is used to transmit rate-of-flow data from interstate gas and petroleum lines (such as the 'Big Inch' pipeline) to central control and monitoring points. Telemetry is used by oil-well loggers to take measurements miles under the Earth's surface, in the midst of tremendous heat and pressure. Of late, however, the term 'telemetry' is usually associated with taking measurements in fast-moving rockets and using these measurements on the ground. There are three parts to a rocket telemetry system: the airborne equipment, the transmission link, and the ground equipment.

2.1. AIRBORNE EQUIPMENT

The heart of the airborne equipment is the transducer, a device which converts energy from one form to another. A good example of a transducer used in rocket applications is the thermocouple, which consists of two wires twisted together. The wires are made from different metals which react together to provide a small voltage output which is proportional to the heat around the wires. Other types of transducers can convert pressure, acceleration, quantity, angular motion, and other important variables into electrical impulses.

Thus the output from the transducer is an electrical impulse which is proportional to the variable being measured (the measurand). To transmit these impulses to the ground, they must be made to influence a radio-frequency (RF) carrier signal. The two most important ways of doing this are to vary the frequency of the carrier (frequency-modulation or FM) or to vary the amplitude of the carrier (amplitude-modulation or AM). When FM is used, the output from the transducer is applied to a voltage-controlled oscillator. This oscillator has the ability to vary its output frequency in proportion to an input voltage, in this case the transducer output. The oscillator output is then used to modulate the RF carrier, and the measurand is thus transmitted back to the ground in the form of frequency variations of the RF carrier. In the AM system, the transducer output is used to vary the amplitude, rather than the frequency, of the RF carrier as was mentioned above. There are a number of different schemes for doing this, but for the purpose of this brochure the pulse-code modulation (PCM) system will be described. This is done later under the heading, "Pulse-Code Modulation (PCM) Telemetry". A second function of the airborne equipment arises from the necessity of handling more than one measurand at once. If it is necessary, for example, to telemeter half-a-dozen critical temperatures, acceleration, pressures at many different points, etc., it is obviously not feasible to use a separate transmitter for each of these measurands. This would mean that most of the rocket's payload

would consist of transmitters; obviously another method must be used. The solution is called time-division multiplexing, or commutation. Each measurand is used, in turn, to modulate the carrier; thus this system requires only one transmitter. The actual commutation is done electrically and the transducers are connected so that a large enough number of samples is taken from the transducer outputs to reflect the measurands accurately.

2.2. TRANSMISSION LINK

The transmission link consists of the transmitter in the rocket, the receiver on the ground, and the space in between. The type of transmission link used depends upon a number of factors such as noise considerations, how much bandwidth may be used, transmitter power, receiver gain, selectivity, and sensitivity, and the type of data being transmitted. Current trends are to make the transmitter as light and compact as possible, for obvious reasons, and to concentrate on making the receiver on the ground (where size and weight are not limitations) do as much of the work as possible. In any case, the function of the transmission link is to get the information from the rocket to the ground with as little static, noise, and distortion as possible.

2.3. GROUND EQUIPMENT

The function of the ground equipment can be summed up by saying that its job is to reverse the steps that the airborne equipment performed on the data. The first part of this function is the acquisition of the data. This includes reconstructing the data to reduce the effects of noise in the transmission link, determining where the data starts and ends for each measurand, and converting the information from serial form (one bit at a time) to parallel form (the information from each measurand available all at once).

The second part of the ground equipment function is decommutation, or sorting out the data from different measurands and applying it to the proper output, or peripheral equipment. This peripheral equipment may be a computer, graphic recorders, binary or decimal counters, tape recorders, oscilloscopes, or automatic printing machines. Thus the peripheral equipment either uses or stores the data which originated as a temperature, pressure, acceleration, or other variable in a rocket, spacecraft, or satellite.

3. PULSE-CODE MODULATION (PCM) TELEMETRY

In PCM telemetry an encoder is used in the airborne equipment to change the analog signals from the transducers to a binary digital form. In the simplest form of this system, a binary ONE is represented by a voltage or current pulse, and a binary ZERO is represented by no pulse. The transmitted signal is then modulated by the binary wave train from the encoder. This system is very reliable because it is a fairly simple matter, on the ground, to distinguish between only two levels of modulation, even in the presence of noise. Also, this system is relatively unaffected by irregularities and non-linearities in the transmission link which introduce noise and distortion. PCM systems permit flexibility in exchanging information bandwidth for number of measurands, plus more efficient use of the RF bandwidth. In addition to these advantages, when using a PCM system the information is already in digital form suitable for most peripheral equipment.

When the National Aeronautics and Space Administration (NASA) decided to use PCM telemetry for their Manned Space Flight Range equipment, EMR was selected to design and manufacture it. EMR 's first entry in the PCM telemetry was the Model 185 Digital Decommutator which was so successful that more than 40 complete Model 185 systems are now in use around the world. Continuing research and development by EMR led to the exceptional capabilities demonstrated by the Model 285 PCM Telemetry Data Processor. The Manned Space Flight Telemetry PCM System I (MSFTP-1) which has been designed and built to NASA's rigid specifications is the latest in EMR 's genealogy of telemetry data processors. Fifteen of these MSFTP-1 stations will be installed around the world so that when NASA astronauts or unmanned satellites are orbiting the Earth, NASA personnel on the ground will be in constant contact with them.

4. MSFTP-1 FUNCTIONAL DESCRIPTION

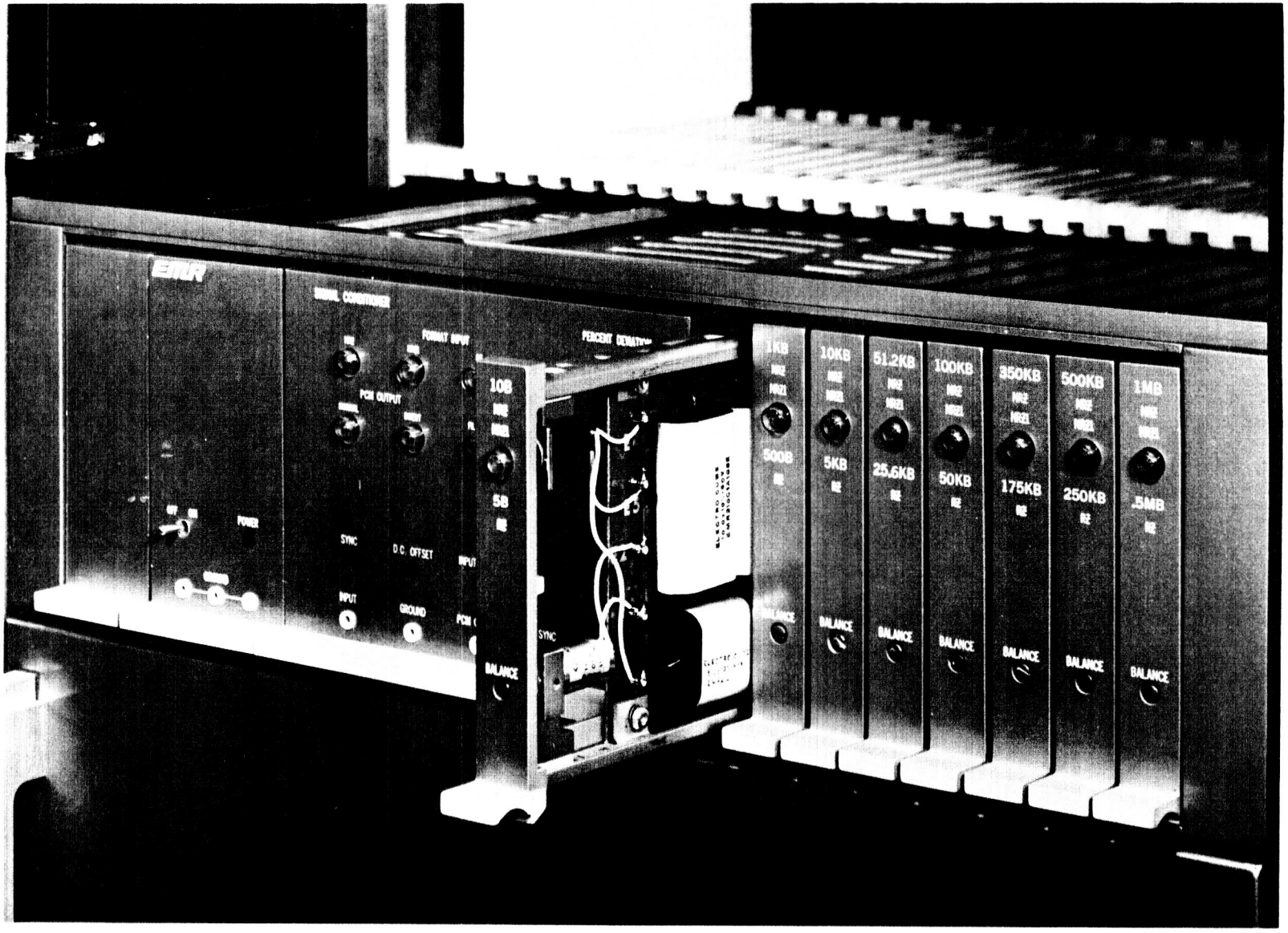
The two basic functions performed by the MSFTP-1 equipment are acquisition and distribution. The purpose of the acquisition function is to restore the received data to an intelligible form which can be readily processed and used. This involves synchronization for time-division mutliplexed (commutated) data. In addition, since PCM transmission is in serial form (one bit of information at a time), there is a need for serial-to-parallel conversion. A great amount of flexibility is required within the acquisition function, since this function must closely match the airborne telemeter format and transmission method which are dictated solely by the purpose and type of mission. The other basic function of the MSFTP-1 equipment, distribution, is the presentation of the data to the user. This function encompasses the decommutation and output (or peripheral) equipment.

4.1. ACQUISITION EQUIPMENT

The acquisition portion of the MSFTP-1 station consists of two distinct parts: the PCM signal conditioner, and the serial-to-parallel converter.

4.1.1. PCM Signal Conditioner

The PCM signal conditioner accepts inputs either directly from a receiver, or from a tape recorder-reproducer. The problem of conditioning a noisy PCM signal is essentially that of locking onto the incoming bit rate (which may be from 10 to 1,200,000 bits per second) and recognizing transmitted ONEs and ZEROs. The PCM signal conditioner has four basic functions: input filtering; DC restoration; limiting; and synchronization. The input filter begins reconstructing the signal by removing noise and otherwise 'cleaning up' the signal. The type of filter used is determined by the transmission method, signal-to-noise ratio, type of receiver used, etc. The filter output is fed to the DC restorer which establishes the median input PCM signal at a particular level so that the decision circuit can perform its task of deciding whether the input voltage is a ONE or a ZERO. The limiter serves to facilitate the bit decision. If the input PCM signal has been DC-restored, the bit-decision problem becomes one of merely determining the polarity of the sample. In this manner the output of the limiter is sampled and the polarity determines whether the code element is a ONE or a ZERO. The purpose of the synchronization portion of the signal conditioner is to provide clock signals for the reconstructed PCM, and also to facilitate the data reconstruction. The basic problem in synchronization is that a non-return-to-zero (NRZ) random-bit pulse train has no discrete frequency components; therefore some nonlinear operation must be performed upon the input PCM to introduce them. In the MSFTP-1 equipment an analog loop is used to introduce discrete frequency components. The loop will acquire and track a bit-rate variation of up to 20% of the nominal design bit-rate with a random-bit PCM input.



ACQUISITION SECTION

EMR MODEL 219 PCM SIGNAL CONDITIONER

4.1.2. Serial-to-Parallel Converter

The serial-to-parallel converter (SPC) accepts the reconstructed serial NRZ PCM data and the bit-timing train from the PCM signal conditioner. The SPC synchronizes on the incoming PCM format and provides various parallel digital outputs and synchronization signals to the distribution portion of the MSFTP-1 equipment.

4.1.2.1. Digital Synchronizers

In the MSFTP-1 equipment, digital synchronizers are provided for word, frame, and subframe synchronization. These synchronizers are programmed to recognize pre-determined sequences of ONEs and ZEROs as valid code patterns. In addition, the frame synchronizer can recognize the sync-code complement, which is the regular code with ONEs exchanged for ZEROs and vice versa. In some formats the regular sync code is alternated with the complement to reduce the probability that relatively unchanging data could appear as a valid code pattern.

These digital synchronizers are designed to acquire sync in as short a time as possible without compromising confidence that the code pattern recognized is valid. These objectives are met by establishing three steps, search, check, and lock, for accepting sync with increasing confidence at each step. The equipment switches from one of these modes to another automatically upon internal logic decisions. The first mode, search, is entered into when the machine is looking for a transmitted code pattern on a bit-by-bit basis. It would not be realistic to look for an error-free code when the signal-to-noise ratio is poor. Therefore, when in the search mode the digital synchronizer can be set to tolerate a number of errors which is variable between zero and nine. Once a code pattern has been found, it must be verified that it appears periodically at the word, frame, or subframe rate depending upon whether it is a word, frame, or subframe synchronizer; this is done during the check mode. As the requirements are less stringent during the check mode, more errors may be tolerated than for search. Therefore an adjustable error threshold is provided for the check mode which is independent of the adjustment for the search mode. The third mode of synchronization is the lock mode, or flywheeling mode. Before switching to the lock mode, it is necessary that the machine logic ascertain the probability of locking on the true sync code. To do this, the machine must be sufficiently flexible to verify the periodic occurrence of the code pattern over any number of periods (words, frames, subframes). Therefore, in addition to the error-threshold adjustment in the check mode, the synchronizer has an adjustment for the number of periods over which the pattern will be checked. The operator has tables to help him optimize settings of the synchronizer. In most cases, adjustments are made to switch to the lock mode with a probability of about 0.98 or 0.99 of having found the true sync-code pattern. The operator is also able to control the 'stiffness' of the flywheeling so that the logic will stay in the lock mode during noise bursts. An independent error-threshold adjustment ensures this. This

adjustment must be set higher than the check mode threshold adjustment. A second control in the lock mode permits the operator to set the number of sequential codes which the machine is permitted to miss. This approach to digital synchronization enables the operator to match exactly the desired synchronization performance which has been derived from computation to meet the specific mission requirements.

The frame digital synchronizer can be programmed to accept the sync code pattern complement. Alternating transmission of the code and its complement is recommended whenever quasi-static data may create lengthy false-synchronization situations. The word synchronizer is slightly different from the frame synchronizer. In the word synchronizer, error counting is not done on a per-code basis, but rather is performed on the total number of errors accumulated while in any given mode.

4.1.2.2. Variable Word-Length Formats

It is very wasteful of information bandwidth to require all words to be the same length. If the words used are all ten bits long for example, and a measurand can be adequately expressed by three bits, seven bits of the word are wasted. Also, the synchronization codes should not be restricted to the same length as the data words (or multiples of the data word length). The length of these code patterns should be determined by computations of the synchronization performance only, and should not be restricted to the data word length. This means that a format which has been optimized should have at least two different word-lengths. The MSFTP-1 equipment is capable of handling words from 4 to 64 bits in length occurring anywhere within the frame; the only restriction is that the words must be the same length from frame to frame.

Variable word-length formatting is a valuable asset; however, it does create problems in the area of serial-to-parallel conversion. When words are of unequal lengths there are two ways to perform this serial-to-parallel conversion. One way is to line up all of the words with their most-significant bits in line; the other way is to line up all of the words with their least-significant bits in line. When the words are lined up on the MSB, they are essentially scaled to a common maximum (or full-scale) value; this is the proper type of presentation to use in driving digital-to-analog converters. When the words are lined up on the LSB, the arithmetic value of the data is preserved. Thus the LSB line-up is used to drive peripheral equipments which accept numerical inputs. In the MSFTP-1 equipment, however, only the MSB line-up is necessary.

4.1.2.3. Binary-to-BCD Converter

The MSFTP-1 equipment has provisions for converting binary outputs into binary-coded decimal (BCD) form. In BCD, four binary digits are used to represent each decimal digit. BCD outputs are frequently used to drive decimal displays; these are much easier to read than binary displays. Also, many digital peripheral equipments require BCD inputs.

4.2 DISTRIBUTION EQUIPMENT

The distribution portion of the MSFTP-1 station is concerned with the presentation of data to the user. This function encompasses the decommutation and output (or peripheral) equipment.

4.2.1. Decommutator

The ultimate use of the data to be decommutated is programmed on a patchboard. There is a separate patchboard for each different mission that the equipment is expected to encounter. Switching from one patchboard to another is done automatically as described later under "Format Switching Function".

4.2.1.1. Supercommutation

Supercommutation of telemetered data is obtained by strapping channels together on the airborne commutator. This is done when it is necessary to monitor some parameter more than once per main frame (a main frame is one revolution of the airborne commutator). The MSFTP-1 equipment has the ability to recognize that these strapped channels are to be distributed to the appropriate peripheral equipment. In the MSFTP-1 equipment the strapped channels are decommutated simply by applying them to an OR logic gate. The output from the OR-gate is then each channel, in sequence, which was originally strapped together in the airborne commutator.

4.2.1.2. Stripping

Stripping consists of selecting a group of channels from specific frames within the subframe of the output multiplex and distributing these selected channel groups to the proper peripheral equipment. In the MSFTP-1 equipment this is done by selecting a group of appropriate channel- and frame-gates in pairs and applying each pair to an AND gate. The gate outputs are then applied to an OR gate, thus defining the selected group. Except for the logical AND function between channel and frame, the stripping capability is similar to strapping and may be substituted for it; however, strapping may not be substituted for stripping.

4.2.2. Peripheral Equipment

The outputs from the MSFTP-1 equipment to the peripheral equipment fall into two groups: readout commands and data readouts.

4.2.2.1. Readout Commands

The readout commands transfer the data into the peripheral equipment. These commands are selected through the distribution patchboards and consist of timing signals, sync status (search, check, and lock) signals, and channel-location numbering signals. In addition, provisions are made to decommutate and store any channel in the primary frame or any subframe. Sixty bits are provided for this function.

4.2.2.2. Data Outputs

The output data from the MSFTP-1 equipment is in three forms: parallel binary, BCD, and analog. All of the required parallel binary data may be read out, on command, either in 64-bit form or using only the 8 most-significant bits. In either case, missing bits are represented by zeros. In addition, any channel within a frame (or subframe) can be transferred to any one of a hundred binary-to-analog converters (BACs). Additional binary-to-analog converters may be selected through use of the patchboards. All of the BACs have a resolution of one part in 256, and are capable of supplying from 0 to +10 volts into a 10,000-ohm load.

4.3. AUXILIARY FUNCTIONS

Three auxiliary functions are provided by the MSFTP-1 equipment to facilitate operation and to increase reliability. These functions are: format switching; self-check and marginal check; and parallel-to-serial conversion.

4.3.1. Format Switching Function

The MSFTP-1 equipment contains programs stored on patchboards which select the proper signal-conditioner plug-in unit and re-arrange the internal logic to comply with different mission formats. This includes adjusting the synchronizers to accept different sync codes, and distributing different data words from the various multiplexes to the peripheral equipment. It is essential, in most cases, to perform this switching at electronic speeds; this is most readily accomplished by electronic switching. Each electronic switch has two signal terminals which may be opened or closed through a control terminal. The switches are operated by connecting the control terminals of the proper switches to a voltage source through use of the patch panel; application of the source voltage to any patch panel thus causes the patched switches to close. Switching the voltage source from one patch panel to another in this manner causes switching between the formats to which the patch panels have been pre-patched.

During a format-switching operation the source voltage is removed from one set of patchboards (a distribution and an acquisition board) and is applied to another set. At the conclusion of this transition the selected patchboard in turn selects the proper plug-in filter for the signal conditioner. After the proper plug-in has been energized, synchronization is acquired in the following order: bit, word, frame, and subframe. After format switching, the time required to obtain bit synchronization is normally a function of the signal-to-noise ratio of the incoming data, and of the difference between the incoming bit-frequency and the center frequency of the signal conditioner's energized plug-in. Acquisition of word, frame, and subframe synchronization for a particular format is a function of the signal-to-noise ratio and of the settings on the synchronizer panel thumbwheel switches. However, if the signal is comparatively noise-free and the incoming bit-rate is about equal to the center frequency of the selected signal-conditioner plug-in, bit phase acquisition is acquired after a few transitions. Furthermore, with the synchronizer panel thumbwheel switches set optimally, frame sync can be acquired within two main frames after format switching, with a good signal-to-noise ratio.

4.3.2. Self-Check and Marginal Check Functions

The self-check and marginal check functions are performed by the following equipment:

1. A printed-circuit card tester which is capable of isolating a malfunction to within a particular stage on the card under test.

2. Marginal checking circuits which are capable of applying high and low power-supply voltages to the equipment to determine which circuits may fail under these marginal conditions. Indicators are provided to alert the operator when the equipment is being tested.

3. A 5-inch oscilloscope which is provided for observing waveforms and for timing signal relationships.

4. A digital voltmeter which is used for checking and adjusting the digital-to-analog converter cards.

5. A pulse generator which is used to set up test conditions in the equipment.

6. A one-megacycle counter which is used for accurate determination of pulse-repetition rates.

7. A PCM signal simulator capable of generating PCM signals with characteristics similar to those expected from operational receivers. This simulator is capable of exercising the complete MSFTP-1 station using five different word-lengths, bit rates from 10 to 1,000,000 bits per second, variable output amplitudes from 0 to ±15 volts, odd or even parity, missing pulses, and all probable combinations of synchronization codes.

These functions are all an integral part of the MSFTP-1 equipment. They permit verification quickly and obviously of the proper operation of the station without necessarily performing a thorough qualification test. Another purpose of these well-integrated simulation and check-out functions is to simplify calibration procedures and therefore render them less vulnerable to human error.

4.3.3. Parallel-to-Serial Converter (PSC) Function

The MSFTP-1 equipment can accept 6 or 13 bits of parallel digital data as a system input. A parallel-to-serial converter is provided to accept this data. The parallel input is fed directly to the PSC where it is converted to serial form. The output from the PSC is serial NRZ PCM data which is then used to drive the serial-to-parallel converter in the same manner as any other data which is shifted into the input shift register.

5. MSFTP-1 PHYSICAL DESCRIPTION

The fifteen MSFTP-1 stations are all quite similar, although some stations are installed on shipboard and the rest in ground installations. The physical description of the MSFTP-1 stations is given in the following paragraphs.

5.1. COMPONENT LOCATIONS

The physical locations of all parts within the MSFTP-1 station are assigned nomenclature in accordance with MIL-STD-16C. Each rack has a unit number from 1 (for the rack on the extreme left as seen from the front of the station) up to 11 (for the rack on the extreme right). Each assembly within a rack has a number prefixed by an "A" (A1, A2, etc.) starting with "1" at the top of the rack (usually a power supply) and ending with 10 or 11 at the bottom of the rack (usually a blower assembly). Each further breakdown, all the way to the component level, has another number prefixed by one or more letters. The components are, of course, prefixed by their standard abbreviations (R for resistor, J for jack, etc.) rather than by an "A". For example, the designation 9A3TB1P37 indicates the following:

9 = Rack No. 9

A3 = The third major assembly from the top in Rack 9

TB1 = The first terminal board within assembly A3

P37 = Pin No. 37 on terminal board TB1

5.2. SYSTEM CONSIDERATIONS

Some of the more important physical considerations of the MSFTP-1 systems are discussed in the following paragraphs.

5.2.1. Signal Wiring

All of the signal wiring in the MSFTP-1 equipment is designed point-to-point, thus eliminating the sliding cables necessary in a drawer-type equipment. The elimination of cables increases reliability and permits faster circuitry to be used. The inter-rack wiring is single-ended and uses a heavy ground bus which is insulated from the rack.

5.2.2. Power Wiring

The MSFTP-1 equipment uses three-phase, four-wire, 120-volt power. This results in a reduced current requirement per phase which, in turn, means reduced current-handling and RFI-filtering problems. The input power line

enters Rack 1 and terminates at a large protected terminal board. From this point the power is fed to a three-pole J-frame circuit breaker set at 160-175 amps. The main magnetic contactor for remote operation is rated at 150 amps and is controlled from the system control panel, where the system POWER ON light is also located. Terminals are provided to parallel this switch for remote operation. From the main contactor, the power is distributed to all racks by copper buses. These buses are located in the rack pedestals and run the entire length of the system. Individual rack supplies are then taken from an appropriate pair of buses and supplied to the rack through an E-frame two-pole circuit breaker set at 15-20 amps. Each rack feeder line is twisted to reduce AC flux fields which are potential sources of RFI. The feeder lines are connected to the individual rack power supplies through a rectangular metal duct which provides electrostatic shielding. The ducts include AC convenience outlets for the operation of external test equipment. The power from the individual rack power supplies (located in the top of each rack except 1 and 11) is distributed down the racks to the assemblies using laminated bus-bar sections. The AC and DC power grounds are tied to the racks at one point only, to eliminate ground-loop problems.

5.2.3. Ventilation

Forced-air ventilation of each rack in the MSFTP-1 stations is accomplished by blowers carefully selected for their reliability, efficiency, and low noise-level. Each blower at the bottom of each rack draws cooling air in through a grille which covers the entire width of the rack. Either closed or semi-closed loops are possible. A filter immediately behind the grille removes dust and foreign matter from the air. The grille and permanent filter can be removed without the use of tools. Each blower rotor rests on permanently lubricated ball-bearings and is driven by a 115-volt 50-60 cycle single-phase motor. A vane is installed in the air-flow path which causes an indicator to light in the event of blower failure. The blowers provide sufficient air circulation to keep the temperature rise within the rack to not more than 10°C above ambient.

5.2.4. Accessibility

The use of approximately 1600 EMR printed-circuit cards in each MSFTP-1 station ensures ready accessibility. Each of these cards is a plug-in unit and can be easily removed from the front (or rear, in some cases) of the rack. If it becomes necessary to test, adjust, or monitor individual components on a printed-circuit card while it is in operation, the card is withdrawn and replaced by an extender card. The withdrawn card is then plugged into the extender card; the card is now back in operation in the circuit with every component on it readily accessible. Test points on the cards are mounted in the plane of the card; thus test points can be monitored without using the extender. In addition to the printed-circuit cards, all other modules including power supplies can be readily removed. All wiring is accessible through the rack doors. None of the components, plug-in or not, need be removed to provide access to the wiring.

5.2.5. Interference Control

Each MSFTP-1 station is specifically designed to suppress radiated and conducted interference in accordance with MIL-I-26600. The suppression is such that the system does not interfere with, and is not influenced by, other well-engineered digital equipment operating in the vicinity. RF filters are used on both the AC input lines and on the input lines to each rack feeder. The AC distribution within each rack consists of twisted wire which is enclosed in a rectangular duct for electrostatic shielding. The rack power supplies are enclosed completely in a metal drawer with shielding over all air openings. The metal drawer is then enclosed in the metal rack for further shielding. DC distribution consists of thin, high-dielectric laminates which leads to cancellation of flux caused by large surge currents occurring when synchronous circuits are set or reset. In addition, these laminates tend to reduce pickup. DC distribution from buses to connectors consists of buses located on adjacent connector pins to minimize the separation of power leads. Also, filter capacitors are placed on each tray between buses.

5.2.6. Reliability

Simplicity of design and operation is a basic feature of the MSFTP-1 equipment. Because of rigorous application of reliability design techniques at the component, circuit, logic, and system levels, the inherent reliability of the MSFTP-1 equipment exceeds 1,000 hours mean time between failures for typical missions.

5.2.7. Environment

The MSFTP-1 equipment can operate in an ambient room temperature from -15° C to +40°C, a relative humidity from 0 to 95 per cent, and an altitude from sea level to 15,000 feet without any damage to the equipment. The equipment can be stored in an ambient temperature from -40°C to +66°C.

5.2.8. Maintenance Capabilities

Maintainability of the MSFTP-1 equipment has been enhanced through EMR's rack-layout concepts and printed-circuit card philosophy. Each system is composed of two-rack sections which are interconnected with panel connectors. Each rack has a door in the rear, and either a panel and partial doors, or a full door, on the front. All panels and doors are hinged to ensure easy access to the interior of the rack. All data-handling circuitry and all power supplies are easily removable for inspection, maintenance, repair, or replacement. All modules are identified, and all components on each module are identified. Important signals are brought to test points on the front of each printed circuit card, and all connector terminals are easily accessible for use as auxiliary test points. All printed-circuit cards may be operated on a card extender to simplify troubleshooting under operating conditions.

Troubleshooting is an important aspect of maintainability, especially in large systems such as the MSFTP-1. This was kept in mind by the EMR design team from the earliest phases of design, and lead to the use of the printed-circuit card concept, the diagnostic check subsystem, the semi-automatic logic-card tester, and all of the other features which contribute to the ease of maintaining this equipment.

5.3. ASSEMBLY CONSIDERATIONS

Some of the more important physical considerations of the assemblies comprising the MSFTP-1 equipment are discussed in the following paragraphs.

5.3.1. Racks

Each MSFTP-1 station consists of eleven racks arranged as five pairs plus a single rack. The paired racks are: 1 & 2, 3 & 4, 5 & 6, 7 & 8, and 9 & 10. Shipping the racks in pairs, completely wired, both facilitates and expedites installation. When the rack pairs are received on the site, all that is necessary is to mount the pairs, bolt them together, connect them together electrically, and connect the blower exhausts at the top of the racks to ducting.

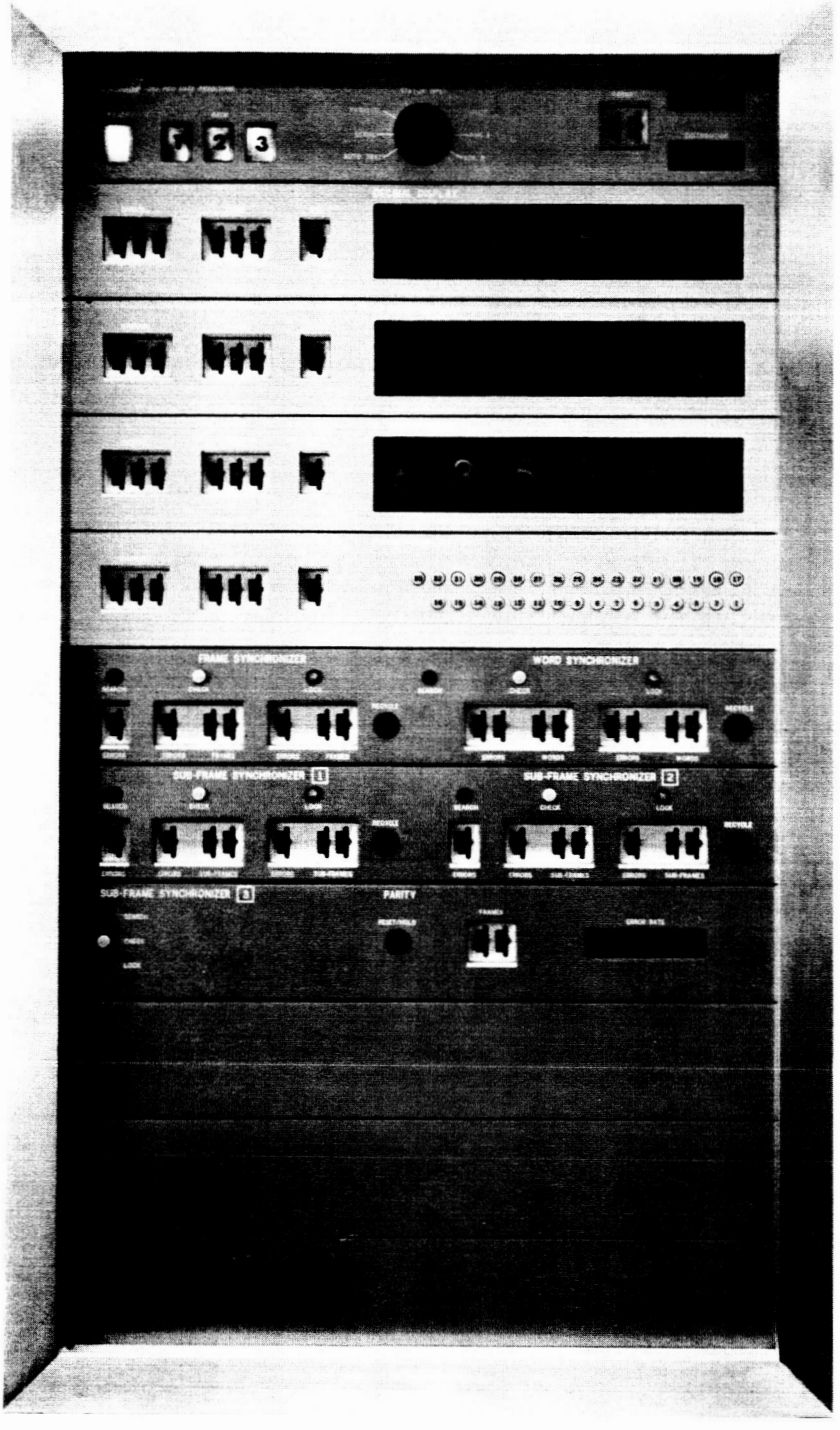
Each rack is 22 inches wide, 24 inches deep, and 76-1/8 inches high (excluding trim strips and side panels), and is a complete welded unit fabricated from cold-rolled steel. All of the commercial equipment (oscilloscope, pulse generator, digital voltmeter, etc.) is mounted in the racks. The panel space provided by each rack is 19 inches wide by 70 inches high. The system controls and indicators are mounted on the front panel of Rack 3.

5.3.2 Files

There are between 65 and 70 printed-circuit card files in each MSFTP-1 system, depending upon how much space is allowed for expansion, modification, and spares storage. Each of these files has provisions for 26 printed-circuit cards. A label is provided at the bottom front of each card slot to identify the card intended for that slot. When a card is inserted into its slot all the way, the male connector at the rear of the card is engaged by a female connector mounted on the file. Each of these connectors has 47 pins for signal and power inputs and outputs to and from the card. Each pin of the female connectors mounted on the files may have a maximum of four leads wire-wrapped to it; all of these connections are readily accessible from the rear of the file (through the rear door of the rack).

5.3.3. Control Panels

As mentioned above, the main system control panel is mounted on the front of Rack 3. This panel is used primarily to control and monitor power and system synchronization; however, digital and binary indicators are also located here for monitoring purposes. The synchronization panels contain



EMR MSFTP-1 SYSTEM CONTROL PANEL

monitor lights which indicate the state of synchronization (search, check, or lock) and thumbwheel switches which are used to set up the synchronization variables according to the input format.

5.3.4. Patch Panels

The MSFTP-1 system uses eight patch panels for programming, four for the acquisition function and four for the distribution function. These patchboards are located on the front of Racks 5,6, 7, and 8 (behind the front doors). Four panels are provided for each function to permit switching from one format to another at a moment's notice. The acquisition patch panel programs such variables as synchronization, bit-rate selection, and position and length of data words. The distribution patch panels control the number of channels per basic frame, the number of basic frames per subframe, stripping, strapping, and storage.

5.4. PRINTED-CIRCUIT CARDS

Of the more than 1600 printed-circuit cards used in each MSFTP-1 station, there are only 22 different types of cards. Some of the tremendous advantages gained from this building-block concept are:

1. Each circuit is standard with respect to inputs, outputs, and impedance levels.

2. The system lends itself readily to marginal checking, since each circuit type has been thoroughly analyzed and tolerances have been established.

3. Fewer subassembly drawings and specifications are necessary.

4. Logistics problems are reduced.

5. A lower unit-cost for components is obtained by virtue of greater quantities being ordered.

6. Fewer engineering man-hours necessary per given system.

7. Greater reliability ensues because each card can be analyzed more thoroughly.

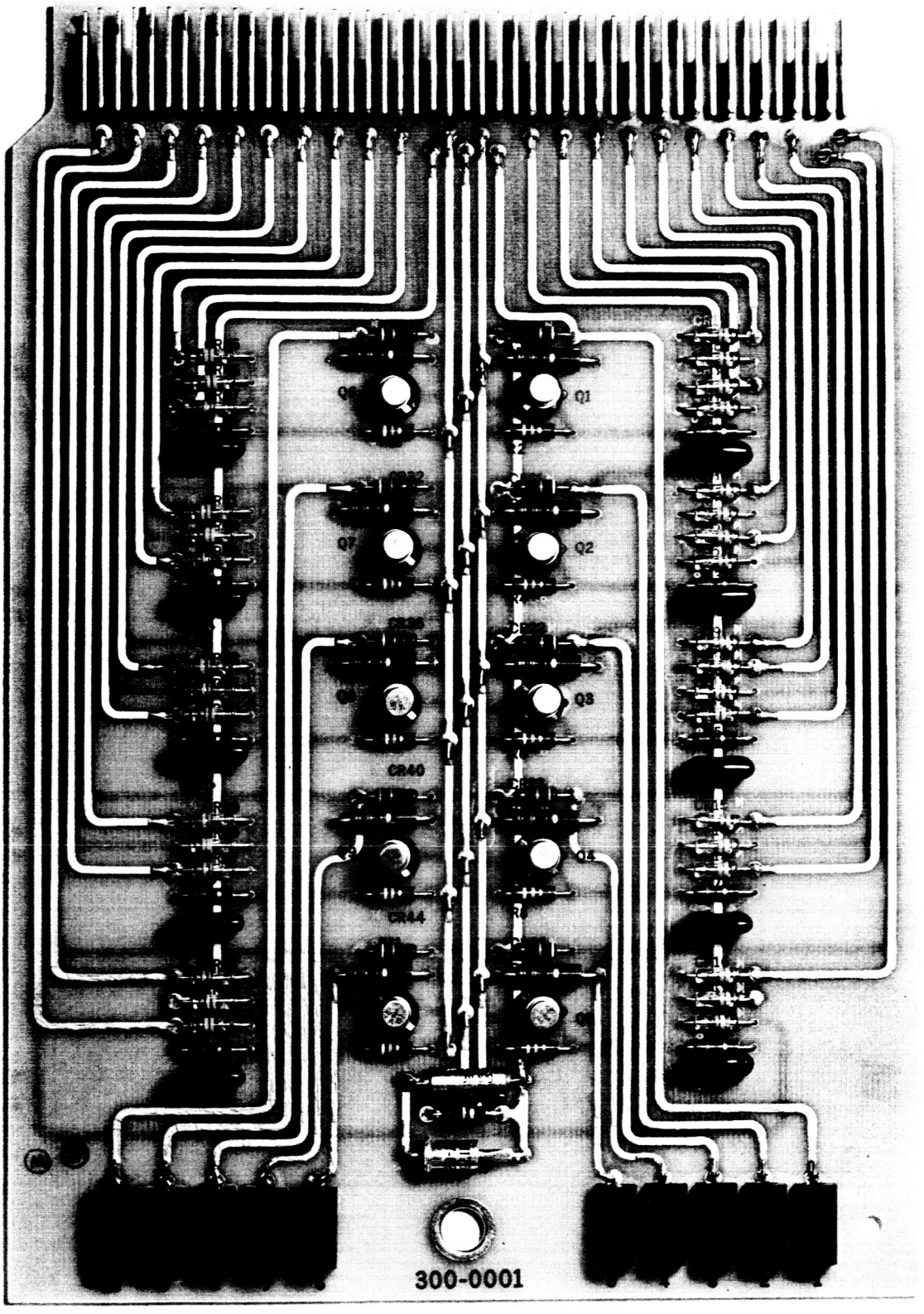
8. Complete subassembly interchangeability is achieved.

9. Production testing is simplified.

10. Production becomes less expensive.

11. Speed of operation of cards is more uniform.

12. Greater flexibility where modifications are necessary.



TYPICAL EMR DIGITAL LOGIC CARD

6. SPECIFICATIONS

The electrical specifications for the MSFTP-1 equipment are divided into two main groups: inputs and outputs. These specifications are given in the following paragraphs.

6.1. INPUTS

The inputs are divided into signal and power inputs. The only power requirement is that it be three-phase, four-wire, 120-volt input power. The amount of power required is approximately twenty KVA.

6.1.1. Signal Inputs

The requirements for the signal inputs are as follows:

1. The bit rate may fall anywhere from 10 to 1,200,000 bits per second.

2. Data words can be from 4 to 64 bits in length.

3. Words may be of different lengths and may occupy any positions within the frame, but word length must be constant from frame to frame.

4. The MSFTP-1 station can accept either forward or backward magnetic-tape playbacks.

5. Word-synchronization codes can be 1, 2, or 3 bits in length.

6. The primary frame can be up to 4,096 bits long.

7. The system can accept any frame-sync code pattern from 7 to 64 bits in length.

8. The MSFTP-1 system can accept any of the NASA-approved forms of PCM (i.e., split-phase, RZ, NRZC, NRZM, or NRZS).

6.2. OUTPUTS

The outputs are also divided into two classes, data outputs and signal outputs. These are described in the following paragraphs.

6.2.1. Data Outputs

The following data outputs are provided by the MSFTP-1 equipment:

1. The maximum parallel output is 64 bits with missing bits

represented by zeros. This data is buffered for computer entry.

2. The eight most-significant bits are also available in parallel binary form. Here again, zeros are used to replace missing bits or words which are less than eight bits long.

3. Parallel binary-coded decimal can be read out at the same time as the binary presentation, on command.

4. Provisions are made for ten BCD stores, with patchboard stripping provisions for an additional ten stores.

5. Any channel of any frame or subframe can be applied to any one of 100 binary-to-analog converters. Patchboard terminal stripping allows for transferring an additional 50 channels for analog conversion. All of the converters have a resolution of one part in 256. The basic analog outputs are from 0 to +10.0 volts into an external 10K ohm load. Twenty outputs are provided with a sense-reversal switch.

6. Sixty four-bit binary positions are provided for storing any decommutated channel from a frame or subframe. A terminal strip and patchboard arrangement provides for an additional 40 ON/OFF stores.

6.2.2. Signal Outputs

The following signal outputs are provided by the MSFTP-1 equipment:

1. Readout commands having in-phase relationship with parallel multiplex data are available for transferring data into peripheral equipment.

2. Word and frame timing signals are provided.

3. Rise and fall times of all output signals are less than 0.1 microsecond.

4. All digital output signals are 0±0.5 volts for a zero, and -6.0 ±1.0 volts for a one.

5. Bits-per-word numbering is available as a seven-bit parallel binary number which is read out, on command, at the same time as the word data.

6. Channel locations within frames or subframes are numbered with a ten-bit parallel binary code and an eleven-bit BCD code. The numbers are read into peripheral equipment, on command, at the same time as the data.

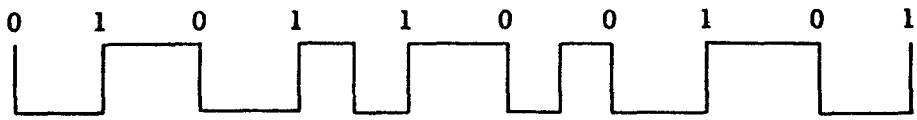
7. Any 100 channel-transfer commands can be selected to permit stripping 100 channels (in a 34, 34, 16, 16 arrangement) from the total multiplex. Any channels from a frame or subframe can be selected; stripping applies to both the binary and the BCD multiplexes.

MANNED SPACE FLIGHT TELEMETRY
PCM SYSTEM I

Appendix A: List of Terms and Abbreviations

A/D	Analog-to-digital
Analog	That which is used to represent something else; e.g., a voltage which varies directly in proportion to a temperature; thus the voltage is an ANALOG of the temperature. An ANALOG system measures; a digital system counts.
BAC	Binary-to-analog converter (or decoder, BAD)
BAD	Binary-to-analog decoder (or converter, BAC)
BCD	Binary-coded decimal; a numbering system wherein each decimal digit is represented by four binary digits. Two forms of this system are used. The 8-4-2-1 form uses four binary counters for each decimal digit. The 2-4-2-1 form replaces the 8 counter with a 2 counter for the MSB. The advantage of the 2-4-2-1 form is that it is self-complementing.
Bi-Phase	See Manchester Code
BRO	Bit-rate oscillator
BSMV	Bistable multivibrator
B/W	Bits per word
C	1. Closed (referring to a gate) 2. Channel (also abbreviated Chan); also called word
CEF	Complementary emitter-follower (also see EF)
C/F	Channels per frame; also called words per frame (W/F)
Chan	Channel (also abbreviated C); also called word
Cmd	Command

CR	1. Channel and rate; a decommutation method consisting of ANDing a basic decommutation rate with a channel gate number to derive the desired subdecommutated channel gate. 2. Diode, when used in conjunction with an Arabic numeral (CR3, CR5, etc.)
D/A	Digital-to-analog
Digital	Represented by a series of discrete counts; see Analog
DO	Digital output
EF	Emitter follower
F	Frame; also called major frame, primary frame, or field.
F0	Timing pulses at the incoming bit rate. A prime sign (F0') indicates pulses midway between F0 pulses. Bar indicates inversion ($\overline{F0}$, or $\overline{F0'}$).
FR	Frame reset pulse
FS	1. Field sync or major-frame sync 2. Full-scale
F.S.	Frame synchronization
I	Inverter
ID	Identification
Inh	Inhibit; inhibited
LO	Local oscillator (also voltage-controlled oscillator, VCO)
LSB	Least-significant bit, usually transmitted last. Also LSD, q.v.
LSD	Least-significant digit; also LSB, q.v.
Manchester Code	A special data-signal bit format wherein each digit one is represented by a certain signal level polarity change (e.g., from positive to negative), and a zero is represented by the opposite polarity change (in the above example, from negative to positive). Also called split-phase or bi-phase data.



Mplx Multiplex, q.v.

MSB Most-significant bit, usually transmitted first; also MSD, q.v.

MSD Most-significant digit; also MSB, q.v.

MSFR Manned Space Flight Range; generic name for NASA's globe-girdling satellite-tracking system.

MSFTP-1 Manned Space Flight Telemetry, PCM System I; generic name for the 11-rack telemetry data processing systems developed and manufactured by EMR for NASA.

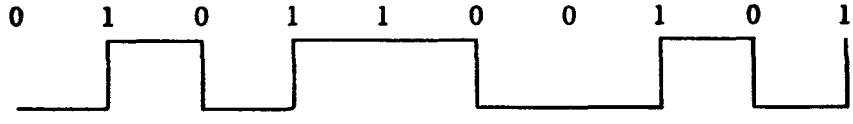
MSMV Monostable multivibrator; also abbreviated MS or TD (trigger delay)

Multiplex A single transmission path which contains data representing two or more variables.

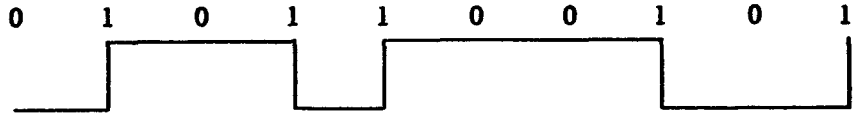
NC Normally-closed; refers to switch contacts

NO Normally-open; refers to switch contacts

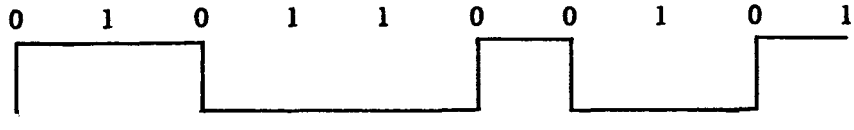
NRZC Non-return-to-zero data signal. A binary data pulse train wherein each digit change is represented by a level transition.



NRZM Non-return-to-zero data signal, special case M. A binary data pulse train wherein each digit one is represented by a level transition.

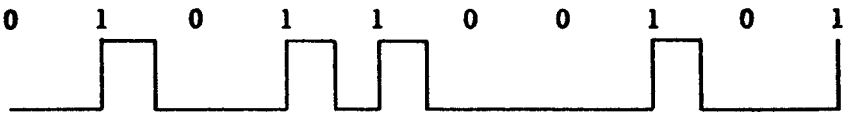


NRZS Non-return-to-zero data signal, special case S. A binary data pulse train wherein each digit zero is represented by a level transition.



OS	One-shot (monostable multivibrator). Also abbreviated MSMV, MS, TD, or D, q.v.
PAM	Pulse-amplitude modulation; an analog telemetry system wherein the information is contained in the amplitude of a transmitted pulse.
PB	Patch board
PC	Printed circuit or printed card
PCM	Pulse-code modulation; a digital telemetry system wherein the information is contained in a series of binary-coded pulses.
PCMA	Pulse-code modulation, asynchronous
PCMS	Pulse-code modulation, synchronous
PDM	Pulse-duration modulation (also PWM, q.v.); an analog telemetry system wherein the information is contained in the duration (width) of a transmittal pulse.
PNM	Pulse-number modulation; a digital telemetry system wherein the information is contained in the number of transmitted pulses.
PPM	Pulse-position modulation; an analog telemetry system wherein the information is contained in the position of one pulse with respect to another pulse; quite similar to PDM.
P/S	Parallel-to-serial
PSC	Parallel-to-serial converter
PWM	Pulse-width modulation; see PDM
Reg	1. Regulated, when referring to power-supply circuits 2. Register, when referring to data-handling circuits
RFI	Radio-frequency interference
RG	Reset generator
RTZ	Return to zero; also abbreviated RZ, q.v.
50% RZ	RZ PCM data with a 50% duty cycle; the illustration under the heading "RZ", is 50% RZ.

RZ	Return-to-zero data signal. A binary data pulse train wherein each digit one is represented by the presence of a pulse and each digit zero is represented by the absence of a pulse.



Ser	Serial
SF	Subframe; also called minor frame, secondary frame, or simply frame
S/N	Signal-to-noise ratio
S/P	Serial-to-parallel
SPC	Serial-to-parallel converter
Split-Phase	See Manchester Code
SPS	Samples per second
SR	Shift register
SRS	Shift-register storage
Telemetry	Literally, "measuring from a distance." The science of collecting information from a remote point.
Tlm	Telemetry
TR	Transfer
Transducer	A device which converts energy from one form to a different form. As used in telemetry, a transducer converts the variable being measured (temperature, acceleration, etc.) into a voltage, current, or frequency proportioned to the variable.
Unreg	Unregulated
VCO	Voltage-controlled oscillator (also local oscillator, LO)
VWL	Variable word-length; a valuable asset of PCM telemetry which permits data and synchronization words to be of different lengths, i.e., to contain different numbers of bits.
W	Word; also called channel (abbreviated Chan)

W/F	Words per frame; also called channels per frame (C/F)
WR	Word rate
WRS	Word-rate sync
W.S.	Word synchronization